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EXHIBIT SELECTION

A Cost-Effective Junior Resident Training and Assessment Simulator for Orthopaedic Surgical Skills via Fundamentals of Orthopaedic Surgery

AAOS Exhibit Selection

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Investigation performed at the Departments of Orthopaedic Surgery, Biomedical Engineering, and Anatomy and Neurobiology, Neuroscience Research Facility, University of California, Irvine, Irvine, California; Department of Orthopaedic Surgery, Washington University, St. Louis, Missouri; and Department of Orthopaedic Surgery, Wake Forest School of Medicine, Winston-Salem, North Carolina

Background: Psychomotor testing has been recently incorporated into residency training programs not only to objectively assess a surgeon's abilities but also to address current patient-safety advocacy and medicolegal trends. The purpose of this study was to develop and test a cost-effective psychomotor training and assessment tool—The Fundamentals of Orthopaedic Surgery (FORS)—for junior-level orthopaedic surgery resident education.

Methods: An orthopaedic skills board was made from supplies purchased at a local hardware store with a total cost of less than \$350 so as to assess six different psychomotor skills. The six skills included fracture reduction, three-dimensional drill accuracy, simulated fluoroscopy-guided drill accuracy, depth-of-plunge minimization, drill-by-feel accuracy, and suture speed and quality. Medical students, residents, and attending physicians from three orthopaedic surgery residency programs accredited by the Accreditation Council for Graduate Medical Education participated in the study. Twenty-five medical students were retained for longitudinal training and testing for four weeks. Each training session involved an initial examination followed by thirty minutes of board training. The time to perform each task was measured with accuracy measurements for the appropriate tasks. Statistical analysis was done with one-way analysis of variance, with significance set at $p < 0.05$.

Results: Forty-seven medical students, twenty-nine attending physicians, and fifty-eight orthopaedic surgery residents participated in the study. Stratification among medical students, junior residents, and senior residents and/or attending physicians was found in all tasks. The twenty-five medical students who were retained for longitudinal training improved significantly above junior resident level in four of the six tasks.

Conclusions: The FORS is an effective simulator of basic motor skills that translates across a wide variety of operations and has the potential to advance junior-level participants to senior resident skill level.

Clinical Relevance: The FORS simulator may serve as a valuable tool for resident education.

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Substantial changes to the classic models of surgical education and training are required secondary to an increased focus on patient safety, expanded skill requirements, restricted work hours, and financial constraints. To address some of these issues, several surgical specialties have adopted new educational modalities, including online curricula and surgical simulation, to educate and train residents in a safe, efficient, and cost-effective manner^{1,2}. Surgical simulation has the promise to be an effective tool in resident education as it offers repetitive psychomotor training and immediate objective feedback in a learner-centered, risk-free environment.

Orthopaedic surgery simulation currently includes cadaver laboratories, synthetic bone exercises, and virtual reality simulators that are costly and unaffordable for many residency programs. To circumvent this issue, our general surgery colleagues have successfully pioneered training tools that utilize low-cost components to simulate real-world exercises. The Fundamentals of Laparoscopic Surgery (FLS) is a validated, cost-effective surgical simulation tool that trains and assesses residents' psychomotor skills in a variety of laparoscopic procedures¹. Moreover, there has been a recent push among other surgical disciplines to develop similar specialty-dependent training modalities to encourage early psychomotor skills and provide an objective measure for resident competency^{3,4}. For example, urology has developed a cost-effective and risk-free simulator that is accessible to both small and large programs.

Orthopaedic surgery has followed the example of its surgical colleagues by both recognizing the need for increased patient safety⁵ and realizing the utility and necessity of surgical simulation^{6,7}. The American Board of Orthopaedic Surgery (ABOS) has implemented surgical skills training modules for all first-year orthopaedic surgery residents. Although recent studies have focused attention on surgical simulation in orthopaedic surgery⁸⁻¹³, there is currently no accepted standardized training and assessment tool analogous to general surgery's FLS program. The purpose of this study was to create and evaluate a cost-effective, standardized resident training and assessment tool for orthopaedic surgery.

Materials and Methods

All procedures involving live human subjects were approved by the institutional review board of the University of California, Irvine; Washington University in St. Louis; and Wake Forest University.

Development of the Fundamentals of Orthopaedic Surgery (FORS)

A questionnaire was initially distributed to twelve board-certified (ABOS) orthopaedic surgeons. This questionnaire aimed to identify the most essential skills that were necessary to become a competent orthopaedic surgeon (Fig. 1). Once the questionnaires were completed, a surgical skills training board (FORS) that included the six previously identified basic and essential tasks was constructed and designed to assess these skills (Fig. 2). The FORS board was constructed from supplies that were purchased at local hardware and home-improvement stores at a total cost of approximately \$350. Although assembly of the FORS board is necessary, it is achievable with minimal effort in a reproducible manner. Each task sought to maximize operative face validity and content validity, as well as create a quantifiable and reproducible way of judging the participant's performance. The six psychomotor tasks developed included

simulation of the following: (1) fracture reduction, (2) minimizing drill depth of plunge, (3) drilling by haptic feedback (i.e., drill by feel), (4) fluoroscopy, (5) correct lag-screw placement or three-dimensional (3-D) drill control, and (6) suturing.

Description of FORS Tasks

Fracture Reduction

The fracture reduction exercise utilizes a PVC (polyvinyl chloride) pipe with an obliquely oriented chevron fracture. The PVC pipe is mounted to a table vise grip on each end. Moreover, one of the table vise grips is placed on a translational board to allow for sliding. As such, these components allow for shortening and rotational forces to be applied to the simulated fracture (Fig. 3-A). Fracture reduction clamps were utilized for the exercise. This exercise was timed until a successful reduction was completed, with a maximum time of 240 seconds allowed.

Depth of Plunge

The depth-of-plunge minimization task was created to simulate a soft tissue-bone interface by using a PVC pipe and a foam block as a backstop. The participant drills five consecutive holes through the PVC pipe, minimizing their plunge through the foam (Fig. 3-B). The exercise was timed and scored on the basis of the depth of plunge in millimeters.

Drill by Feel

The drill-by-feel accuracy task simulates drilling in the absence of direct visualization of a target, such as in external fixator pin placement. A flat 3.8-cm-wide board with a line bisecting the width was wrapped cylindrically with foam, thus hiding the board, and was mounted to the FORS testing board. The participants must use only the drill bit to accurately assess the center of the wooden board (Fig. 3-C). This task was timed and scored on the basis of the distance from the center of the board.

Fluoroscopy

The fluoroscopy simulation task requires the participant to aim a drill-bit through a premarked 3.8-cm-thick block of wood with color-coordinated visible entry points vertically and horizontally (Fig. 3-D). The participant triangulates the covered exit point by using color-coordinated guide-marks on perpendicular planes of the block. This exercise was timed and scored on the basis of the exit point's distance from the premarked location. This task highlights the importance of using fluoroscopy to properly triangulate a point that cannot be visualized.

3-D Drilling

The 3-D drilling and lag-screw-placement task requires participants to aim a drill-bit through a 3.8-cm-thick block of wood with three different color-coordinated entry and exit points (Fig. 3-E). In this task, each color is drilled individually, with planning for each screw allowed. This exercise was timed and scored on the basis of the distance of the exit point from the premarked location.

Suturing

Suture speed and quality were assessed by giving each participant 240 seconds to place as many simple, interrupted sutures as possible into a PVC pipe-mounted foam incision (Fig. 3-F). Sutures were required to have three throws per knot via instrument ties, as well as self-cutting and reloading of the suture. Only sutures that were able to hold tension without unraveling were counted, although closure and approximation of the incision were not required. Scores were recorded as the number of sutures.

Scoring

Each exercise was scored on the basis of efficiency (time) or efficiency and accuracy (penalty). A maximum time was given for each task. A time score was

FUNDAMENTALS OF ORTHOPAEDIC SURGERY

Thank you for taking part in our survey. The goal of this survey is to utilize your input to help build a curriculum in order to improve resident education and knowledge base. Please take the time to fill out the questionnaire below.

Name:
University Affiliation:
Position: Faculty

In order to provide quality patient care, what level of intraoperative skill proficiency is required for the graduating Orthopaedic Surgery resident to have in each of the following areas?

- 1 = Skill is mastered, able to provide guidance to others
 3 = Able to perform task independently, but will occasionally need assistance
 5 = Understands basic techniques/knowledge, but needs help performing task

Category: Surgical Skills	Value				
	Mastered		Intermediate		Novice
Patient Positioning	1	2	3	4	5
Correct placement of incision	1	2	3	4X	5
Scalpel Control	1	2	3	4	5
Soft tissue dissection of vessel/nerve	1	2	3	4	5
Fluoroscopy comprehension	1	2	3	4	5
Drill control under fluoroscopic view	1	2	3	4	5
Reduction techniques	1	2	3	4	5
Correct placement of lag screw	1	2	3	4	5
Drill control with lag screw placement	1	2	3	4	5
Appropriate placement/alignment of plate	1	2	3	4	5
Appropriate plating technique for fracture (Neutralization, bridging, etc.)	1	2	3	4	5
Intramedullary canal reaming/preparation	1	2	3	4	5
Appropriate blocking screw placement	1	2	3	4	5
Limiting plunge while drilling	1	2	3	4	5
Drilling by tactile feedback	1	2	3	4	5
Spatial understanding of drill trajectory	1	2	3	4	5
Suture needle control	1	2	3	4	5
Able to perform tasks with both hands	1	2	3	4	5
Tissue Approximation	1	2	3	4	5

Fig. 1

Attending physician questionnaire. The highest rated skills incorporated into the simulation board are highlighted.

calculated by subtracting the participant's time from the maximum time. Accuracy was assessed on the basis of measured distances (in millimeters) from the desired point and multiplied by a constant factor. The accuracy score was subtracted from the time score to give the final result. When a negative score was received, a recording of zero was used.

Forty-seven medical students, fifty-eight orthopaedic surgery residents, and twenty-nine attending orthopaedic surgeons from three ACGME (Accreditation Council for Graduate Medical Education)-accredited orthopaedic surgery residency programs participated in the study. At each training site, replica FORS boards were built from materials purchased at local

TABLE I Scores on the Six Tasks Tested with the FORS Simulation Board*

	Medical Students	Medical Students Trained	Junior Residents	Senior Residents	Attending Physicians
Fracture reduction	98.78 ± 11.60	213.10 ± 8.55	191.60 ± 6.18	219.80 ± 2.09	220.10 ± 2.87
Depth of plunge	9.10 ± 2.10	46.78 ± 3.53	24.50 ± 4.82	50.68 ± 4.05	52.14 ± 3.67
Drill by feel	20.91 ± 3.28	65.32 ± 3.51	42.14 ± 3.66	62.90 ± 3.33	53.95 ± 4.13
Fluoroscopy	13.35 ± 2.12	39.10 ± 3.79	10.22 ± 2.41	26.84 ± 2.90	25.14 ± 3.73
3-D drilling	30.47 ± 2.74	39.80 ± 3.44	35.52 ± 3.77	51.57 ± 1.88	48.85 ± 2.95
Sutures	2.94 ± 0.27	7.27 ± 0.34	7.47 ± 0.36	10.60 ± 0.31	10.48 ± 0.36

*The values are given as the mean and the standard error of the mean.

hardware stores. Additionally, twenty-five medical students were retained for longitudinal training and testing weekly for four weeks. Each training session was thirty minutes long and instructed by a senior-level orthopaedic surgery resident. Data are presented as the mean and standard error. One-way analysis of variance with a Bonferroni post hoc comparison was performed unless otherwise indicated. A *p* value of <0.05 was considered significant.

Results

Questionnaire Results

On the basis of the questionnaire answered by orthopaedic surgeons (Fig. 1), the highest rated skills necessary for a competent orthopaedic surgeon were fracture reduction, minimizing depth of plunge, drilling by tactile feedback, directional control of the drill, fluoroscopic drilling, correct lag-screw placement, and soft-tissue closure. These skills were thought to be applicable across a wide variety of orthopaedic procedures. As a result of this questionnaire, the FORS surgical skills board was created to incorporate these tasks for training and evaluation (Fig. 2).

Fracture Reduction

Compared with all other participants, untrained medical students had difficulty reducing the fracture (98.78 ± 11.60 ; $p < 0.0001$) (Table I, Fig. 4-A). Furthermore, junior residents performed significantly slower than senior residents (191.60 ± 6.18 versus 219.80 ± 2.09 ; $p = 0.003$). Trained medical students demonstrated significant improvement in their scores, which were also improved compared with junior residents (213.10 ± 8.55 versus 191.60 ± 6.18 ; $p < 0.05$). For the fracture reduction exercise, novice participants were able to achieve scores significantly better than junior residents and on par with senior residents after four weeks of training.

Depth of Plunge

The scores for novice medical students (9.10 ± 2.10) were significantly lower than those for all other groups when performing this task ($p < 0.0001$) (Table I, Fig. 4-B). In addition, junior residents scored significantly lower than senior residents (24.50 ± 4.82 versus 50.68 ± 4.05 ; $p < 0.0001$). Similarly, the scores for trained medical students (46.78 ± 3.53) were significantly better than those for junior residents as well ($p < 0.001$), with scores on par with those for senior residents.

Drill by Feel

Medical students were initially unable to drill by tactile feedback accurately, and therefore, their scores (20.91 ± 3.28) were significantly below those of all other participants ($p < 0.0001$) (Table I, Fig. 4-C). Moreover, senior residents significantly outperformed junior residents in this task (62.90 ± 3.33 versus 42.14 ± 3.66 ; $p < 0.001$). Similarly, once medical students were trained to perform this task properly, their score (65.32 ± 3.51) was significantly higher than that of junior residents ($p < 0.0001$). In fact, their score was higher than that of senior residents as well.

Fluoroscopy

The scores on the fluoroscopy test were significantly lower for medical students (13.35 ± 2.12) and junior residents (10.22 ± 2.41) than for senior residents (26.84 ± 2.90 ; $p < 0.01$) (Table I, Fig. 4-D). However, trained medical students were able to improve their scores significantly (39.10 ± 3.79 ; $p < 0.05$), not only above those of junior residents but also above those of senior residents.

3-D Drilling

On initial testing with 3-D drilling, both medical students and junior residents (30.47 ± 2.74 and 35.52 ± 3.77 , respectively) were significantly outperformed by senior residents (51.57 ± 1.88 ;

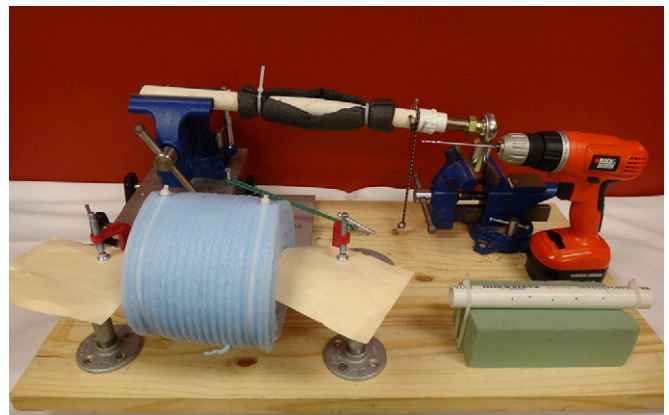


Fig. 2

The Fundamentals of Orthopaedic Surgery (FORS) simulation board.

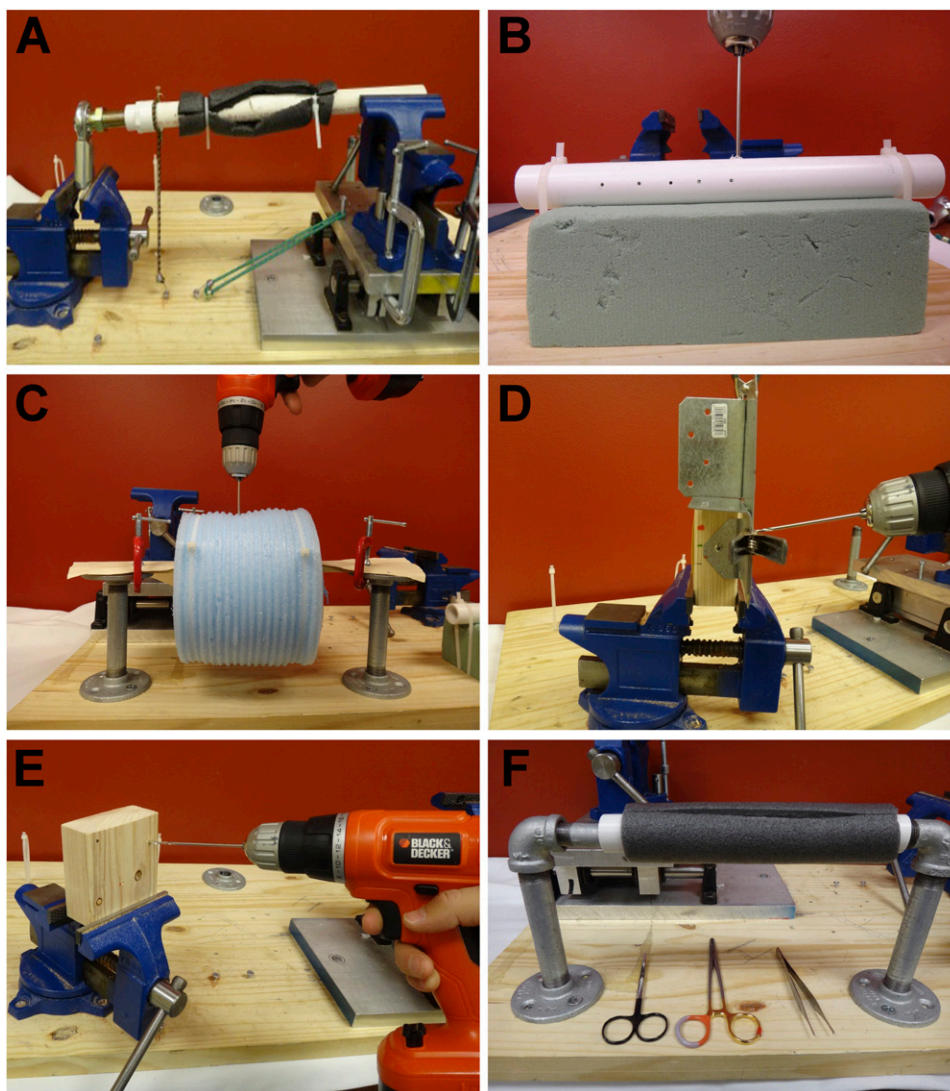


Fig. 3

Figs. 3-A through 3-F Photographs showing the six tasks that are tested by the FORS simulation board. **Fig. 3-A** The fracture reduction task, which utilizes shortening and rotational forces to simulate intraoperative fracture reduction. **Fig. 3-B** The depth-of-plunge minimization task, in which the participant learns to restrict the depth to which he or she plunges past the plastic PVC pipe. **Fig. 3-C** The drill-by-feel task, in which the participant utilizes tactile feedback from the drill to guess where the center of the longitudinal width of the board is located. **Fig. 3-D** Fluoroscopic simulation, which is performed with the participant drilling from a known start point to a covered exit point by using two reference points perpendicular to each other on a block of wood. **Fig. 3-E** The 3-D drilling task simulates lag-screw placement as the participant drills from a visible start point to a visible exit point. **Fig. 3-F** The suturing exercise utilizes PVC pipe insulation as the soft-tissue envelope to simulate wound closure.

$p < 0.01$) (Table I, Fig. 4-E). However, in this task, even when medical students were trained, they were unable to significantly improve their scores (39.80 ± 3.44). Thus, it is likely that certain tasks are unable to be replicated and simulated outside real-world experience and procedures.

Suturing

On initial assessment of their suturing ability, most medical students had not been previously taught how to properly suture and instrument tie. As a result, the scores for medical students (2.94 ± 0.27) were significantly lower than those for all other

groups of participants ($p < 0.0001$) (Table I, Fig. 4-F). Moreover, junior residents were able to tie significantly fewer sutures than senior residents were in the allotted time period (7.47 ± 0.36 versus 10.60 ± 0.31 ; $p < 0.0001$). After medical students were trained in proper suturing techniques, they were able to significantly improve their scores (7.27 ± 0.34) to the level of junior residents. However, they were unable to reach the level of senior residents. Again, this is likely due to the experience that residents gain in suturing throughout the operating-room experience, and this skill likely requires a longer time period to improve to that upper echelon of scores.

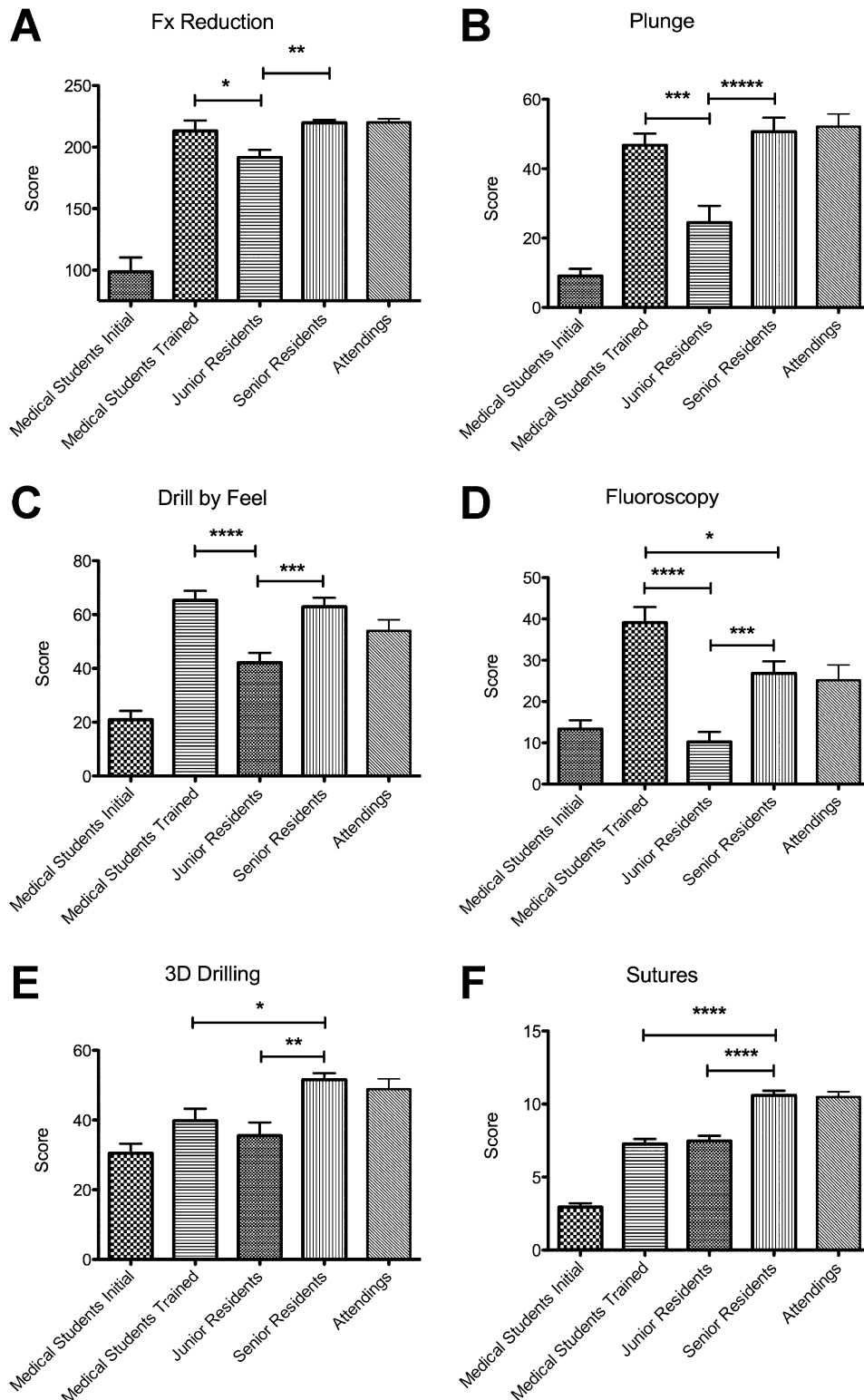


Fig. 4

Figs. 4-A through 4-F Graphs showing the scores for medical students, medical students after a training course, junior residents, senior residents, and attending physicians. Data are presented as the mean and the standard error of the mean. **Fig. 4-A** Fracture reduction results. * $P < 0.05$. ** $P = 0.003$. **Fig. 4-B** Depth-of-plunge results. *** $P < 0.001$. **** $P < 0.0001$. **Fig. 4-C** Drill-by-feel results. *** $P < 0.001$. **** $P < 0.0001$. **Fig. 4-D** Fluoroscopy results. * $P < 0.05$. *** $P < 0.01$. **** $P < 0.05$. **Fig. 4-E** 3-D drilling results. * $P < 0.01$. ** $P < 0.01$. **Fig. 4-F** Suturing results. **** $P < 0.0001$.

Overall, stratification among medical students, junior residents, and senior residents and/or attending physicians was found in all tasks after testing on the FORS board.

Discussion

The current medicolegal climate and public perception of patient safety both restrict the ability of the junior resident to learn basic operative skills inside the operating room. As such, it is critical that there is appropriate training outside the operating room in a simulated and patient risk-free environment¹⁴⁻¹⁷. In regard to orthopaedic surgery, a simulator is an ideal tool for hands-on learning. Simulation allows for repetitive practice of a particular skill with immediate feedback. As the task is repeated over an extended period of time, long-term structural modifications occur in the brain^{18,19}. Furthermore, simulation allows for regular interval training to accelerate acquisition of correctly performed motor skills, thereby increasing the learner's ability to retain those skills and building learner confidence in a low-stress environment^{20,21}.

There is ample evidence in surgical subspecialties to support surgical simulation for the learning and acquisition of new skills as well as improving operative performance. In regard to simulation for orthopaedic surgery, there are a small number of virtual reality simulators that can serve as an alternative to standard cadaver laboratories and synthetic bone exercises^{22,23}. However, most residency educational programs do not have substantial disposable income and must carefully scrutinize each training tool to determine if it will be maximally beneficial to resident education.

The FORS simulator was developed to help increase the practice of relevant orthopaedic tasks by junior residents in a cost-effective manner and thereby allow universal access to all residents. The overall importance of the FORS simulator is that it allows for multiple repetitions of important orthopaedic skills in a short period of time with objective feedback. As many junior residents may have had limited access to an operative drill while on an orthopaedic surgery rotation, they will be able to perform multiple repetitions of pertinent motor skills with a minimal time investment with the use of this simulator. Once developed at a site, this simulator is available for use at any hour of the day and thereby allows residents to train at their own pace in a low-stress environment.

The strength of the FORS simulator is the ability to train novice participants to improve above the performance level of junior residents (postgraduate years 1 and 2) on the simulator. Although medical students had initially scored significantly lower than our more senior cohorts, data on our trained medical students demonstrated overall improvement as well as significant improvement above junior resident scores in four of six exercises with only four weeks of training in short regular intervals. The two tasks with results that did not reach significance were 3-D drill control and suturing. Although the improvement in the scores on the 3-D drilling task did not achieve significance, there was a trend in the overall correct alignment and significant results would likely be achieved if the training period extended beyond the four-week block used in this study. Suturing, a task commonly performed by

junior residents, was the one of these two skills that the medical students were unable to improve on. This was expected as junior residents routinely suture in the operating room.

Face validity, the ability for the simulator to contain realism, was tested with the use of materials purchased from local hardware stores. Many of the tasks involve drilling through a material that is not hollow and does not have the same density or thickness as bone. This distracts from a realistic operating-room experience. Although cylindrical objects were used initially on most of the tasks, no significant difference in accuracy was able to be ascertained. The blocks of wood help to increase distance as well as increase participant error, allowing for stratification within our testing population. The principles of triangulation and drilling, which include spatial awareness and coaxial movements with the drill-bit, are maintained with these exercises. With the use of these materials, the simulator cost is below \$350, and all parts for each task are able to be resupplied at local hardware stores, allowing for unlimited repetitions.

Lastly, although we had a total of 134 participants, the medical student group was the largest, at forty-seven. In order to draw more significant conclusions, larger participant numbers need to be obtained. In regard to our attending physician group, nearly all of the attending physicians at each institution participated (those who were not available were not tested); however, there were no community physicians within the testing group.

In conclusion, the FORS, which includes six psychomotor tasks that cross over a multitude of orthopaedic surgeries, objectively demonstrated that attending physicians and senior residents performed on average at a higher level than junior residents and novice medical students. Longitudinal training of medical students demonstrated that this could be an important training tool for resident education. Ultimately, it is our hope that junior-level orthopaedic surgery residents learn motor skills intrinsic to orthopaedic surgery on low-cost simulators prior to performing operations on patients. ■

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